PRESERVATION OF BODY PROTEIN

FIELD OF THE INVENTION

The present invention relates to the preservation of body protein stores in patients being in a catabolic state.

5 BACKGROUND OF THE INVENTION

Glutamine is one of the predominant amino acids in the body and constitutes more than 50 % of the total intracellular free amino acid pool in skeletal muscle. It is utilised mainly as an energy source and nitrogen carrier. During postoperative and posttraumatic catabolism its availability is decreased. This results in depletion of

10 skeletal muscle glutamine and, with continued utilisation of glutamine by the intestine, also to low blood glutamine levels. α-Ketoglutarate (α-KG), the biologic precursor of glutamine, has been tried in human enteral and parenteral nutrition. In clinical studies, parenteral and enteral administration of α-KG was claimed to prevent severe muscle protein breakdown (1-4), and to promote mucosal repair in the

15 small intestine (5) and wound healing (6). These recorded effects have been small and judged to be of minor importance. Therefore dipeptides of glutamine and, e.g., serine or alanine, have been used instead. Glutamine turnover after trauma, sepsis or surgery is characterised by muscle protein catabolism and concomitant draining of the muscular free glutamine store to meet the increasing demand of fast dividing

20 cells, e.g. enterocytes, immune cells and fibroblasts. During acidosis and starvation, the liver participates in pH homeostasis by switching from urea to glutamine synthesis (7-9). This is achieved by a decreased periportal utilisation of bicarbonate

in the urea cycle, leaving ammonium (NH_4^+) available for perivenous hepatic glutamine synthesis.

Ammonium is occasionally administered to patients in the form of a pharmacologically acceptable salt such as the chloride in spite of ammonium being considered neurotoxic in that high concentrations is known to be neurotoxic. Therefore its recommended pharmaceutical uses are few. However, as it causes metabolic acidosis it is given by slow infusion in form of the chloride in severe metabolic alkalosis. It is however still considered to be one of the key mediators of hepatic encephalopathy (14). Tissues known to be capable of detoxifying ammonia/ammonium include skeletal muscle, the liver, and the kidneys. In skeletal muscle, about 50% of arterial ammonium content is metabolised (15, 16). The amination of α-KG by glutamate dehydrogenase produces glutamate from which, catalysed by glutamine synthetase through the addition of one amide group, glutamine is formed. Under physiological conditions there is a hepatic uptake of glutamine which is hydrolysed through the action of periportal glutaminase to glutamate and ammonium, the latter being utilised in urea synthesis. During experimental acidosis caused by high ammonium levels, *de novo* synthesis of glutamine, catalysed by glutamine synthetase, takes place in perivenous hepatocytes (17, 18). In the kidneys, ammonium (NH_4^+), is liberated from its main transport form, glutamine, and excreted into the urine (19).

The administration of glutamine and/or small peptides comprising glutamine residues to a patient being in a state of glutamine depletion thus is a less than direct way of coping with such deficiency since glutamine is poorly soluble in water and cannot be sterilised by autoclavation while dipeptides are costly. A more direct way of preserving or raising blood glutamine levels thus is highly desirable.

OBJECTS OF THE INVENTION

It is an object of the present invention to provide an improved method for preserving body protein stores in a patient being in a catabolic state by inducing endogenous synthesis of glutamine.

It is another object of the present invention to provide an improved method for preserving body protein stores in a patient being in a catabolic state by inducing endogenous synthesis of arginine.

It is a further object of the present invention to induce such endogenous synthesis in a manner such as to avoid exerting an extra metabolic strain on the patient.

It is a still further object of the present invention to provide a means useful in carrying out the method.

Additional objects of the invention will become apparent from the following summary of the invention, the description of preferred embodiments thereof, and the appended claims.

SUMMARY OF THE INVENTION

The present invention is based on the hypothesis that combined administration of α-ketoglutaric acid and ammonium ion to a catabolic patient protects bodily protein stores and especially muscle protein from breakdown, that is, from being used as a source of free glutamine. The term "catabolic state" includes conditions in which glutamine stores are depleted or at risk of being depleted, such as in a patient in intensive care, etc. The term "catabolic state" also includes conditions in which arginine stores are depleted or at risk of being depleted, such as in a patient in intensive care, etc.

This hypothesis was tested in an anaesthetised piglet model to which a combination of α-ketoglutaric acid (α-KGA) and ammonium ion were given by

intravenous infusion. The term "in combination" here refers to the administration of α-ketoglutaric acid and ammonium in temporal dependence of each other, the one or the other or both being administered continuously or intermittently.

The synthesis of glutamine/protection against protein breakdown in the

5   animal model was assessed by measuring plasma glutamine concentration and glutamine release from hind leg skeletal muscle and the splanchnic area. In this "minor trauma" model, the effects of different dosages of intravenously administered α-KGA and ammonium chloride on plasma concentration and splanchnic and hind leg skeletal muscle turnover of glutamine, glutamate, alanine, arginine, urea and

10   ammonium were investigated.

Although numerous formulations of varying composition containing α-KG are disclosed in the art to be useful in preserving protein stores in a catabolic state, the present inventors have not found any reports on the combined effects of α-KG and/or α-KGA and ammonium ion on the important amide/ammonium source

15   glutamine.

The present inventors investigated the dose-response effects of intravenous administration of α-KGA and ammonium, especially the immediate effects on the splanchnic and skeletal muscle turnover as well as plasma concentrations of glutamine, glutamate, alanine, arginine and ammonium.

20   Thus, according to the present invention, is disclosed a method of preserving bodily protein stores such as skeletal muscle mass in a catabolic patient, comprising the concomitant administration α-KG and/or α-KGA and ammonium in amounts effective in preserving skeletal muscle.

In the aforementioned animal model, the present inventors found that

25   infusion of α-KGA and ammonium increased arterial glutamine concentration dose-dependently when the ammonium load was increased and the dose rate of α-KGA

was kept constant (Group 2) but not if the dose rate of α-KGA was increased and the ammonium dosage was held constant (Group 1).

Thus, in the method of the invention, it is preferred to conduct the administration of α-KG and/or α-KGA and ammonium concomitantly.

According to the invention it is also preferred for the concomitant administration of (a) α-KG or α-KGA and (b) ammonium to last for more than one hour, more preferred for more than 6 hours but less than 36 hours.

According to a preferred aspect of the invention, a patient having undergone accidental trauma or surgery is treated by the method of the invention, intermittently or continuously, during a substantial portion of the posttraumatic/ postoperative period in which (s)he is in a catabolic state, such as during three days or more.

A preferred constant dosing rate of α-KG or α-KGA in the method of the invention is from about 0.5 $\mu mol \cdot kg^{-1} \cdot min^{-1}$ to about 15 $\mu mol \cdot kg^{-1} \cdot min^{-1}$.

A preferred constant dosing rate of NH_4^+ in the method of the invention is from about 1 $\mu mol \cdot kg^{-1} \cdot min^{-1}$ to about 10 $\mu mol \cdot kg^{-1} \cdot min^{-1}$, the increase over a period of administration being preferably by a factor of from 2 to 5.

It was surprisingly found that the elevated arterial glutamine concentration was not associated with an increased release of glutamine from skeletal muscle or the splanchnic region, suggesting other tissues to be responsible for the increased plasma concentration of glutamine.

The experimental model used in this study represents a minor trauma inasmuch as the surgical interventions was limited to a few small incisions of the skin and the tissue damage therefore was kept to a minimum added to the stress of being anaesthetised. This being so, it can be assumed that the experimental set-up did not induce alterations in plasma concentration of amino acids otherwise seen after major (but not minor) surgery (11). The experimental period was short, only four hours, and while it may be argued that it was too short for changes in the

metabolism of proteins to manifest itself, earlier reports (11, 12) have shown decreased plasma concentration of glutamine as early as 1½ -2½ hours after skin incision in patients undergoing major surgery. Our wish to elucidate the effects of the substrate administration under non-trauma conditions refrained us from including

5   kidney and liver turnovers in the present study. The baseline measurements of hemodynamic and respiratory variables were found to be within the normal range (13) compared to conscious piglets of this size and age.

      Significant effects on the plasma concentration of the amino acids under study were observed. The arterial glutamine concentration in Group 1 and Group 2

10   demonstrated different development (Fig. 2). After 60 minutes, that is after one hour of ammonium chloride infusion (Group 1), or after one hour of α-KGA infusion (Group 2), the glutamine level was increased in Group 1 but decreased in Group 2. The increase in Group 1 may be attributed to the normal response of the liver to enhance glutamine synthesis when the ammonium load is increasing. The increase

15   after 60 minutes was however transient. For the rest of the experimental period there were no differences compared to the baseline glutamine level. This demonstrates that added α-KGA in increasing dosages has no effect on arterial concentration of glutamine. This is in line with the findings of other investigators (21), but it does not rule out beneficial effects of α-KG or α-KGA supplementation. In a review article,

20   Cynober (22) suggests that α-KG preserves endogenous glutamine stores, which may explain the non-existence of increased release of glutamine from skeletal muscle observed in the present study.

      In Group 2, glutamine concentration dropped 9 ± 2 % after one hour of α-KGA infusion compared to the baseline level, a fact that cannot be readily

25   explained, while commencement of ammonium chloride administration caused arterial levels of glutamine to increase in a dose-dependent manner by 73 ± 8 % compared to the lowest value (60 min). Hind leg exchange data (Fig. 4) do not

explain this increase. Although hind leg arterio-venous differences for glutamine did increase, there was no increased net release of glutamine, explicable by a decreased femoral artery blood flow. The reduced hind leg blood flow was not related to lower cardiac output but probably the effect of a redistribution of cardiac output. Data for splanchnic blood flow support this explanation, at least in Group 2, but only partially in Group 1. The fact that the splanchnic glutamine uptake increases in Group 2 during the last two hours of substrate infusion (Fig. 3) indicates a possibility that the liver may not, at least not alone, be responsible for the elevated glutamine levels. It is, however, possible that an increased net splanchnic regional uptake could conceal an increased release by the liver by a quantitatively larger uptake by the intestines. In support of such an interpretation it may be noted that hepatic vein glutamine concentration data indicate an increased synthesis. Furthermore, both arterial and hepatic venous urea concentration was increased in Group 2, disclosing an enhanced urea synthesis. This circumstance is in accordance with the known zonal localisation of the hepatocytes (23), with periportal hepatocytes containing urea cycle enzymes at the inflow, and the perivenous hepatocytes acting as scavenger cells for ammonium, at the outflow from the liver acinus.

Plasma concentration of glutamate in Group 1 was, like glutamine, unaffected by the substrate infusion and in Group 2 there was an increase after 120 min, which was maintained for the duration of the experiment, compared to baseline. A possible interpretation of these results is that the glutamate concentration is controlled by a continuous amidation to glutamine. Turnover data for glutamate does not preclude such an interpretation.

Alanine is a gluconeogenic amino acid and, as could be expected, plasma concentration of alanine decreased in both Groups in order to maintain blood glucose levels.

Some mention of the fate of parenterally administered ammonium is in place. Normally, enteral ammonium is produced from the digestion of proteins and bacterial hydrolysis of urea. It is absorbed by the gut and after reaching the portal circulation, it is efficiently removed by the liver. Some of the parenterally

5   administered ammonium, on the other hand, escapes the detoxifying action of the liver, and contributes to higher plasma concentration.

In both Groups, the splanchnic ammonium uptake mirrored the delivered ammonium dosage. Skeletal muscle uptake, however, presented some unexpected findings in Group 1. After 60 minutes of ammonium infusion, a maximum uptake

10   was reached only to be followed by a continuous decrease with gradually increased α-KGA dosages. The reason for this is unclear, but it might be due to α-KG, above a threshold concentration, counteracting ammonium uptake.

The invention will be more fully understood by studying a detailed description of a number of preferred embodiments illustrated by a number of Figures.

15   ## SHORT DESCRIPTION OF THE FIGURES

Fig. 1 is a timeline for the NH_4^+/a-KGA administration protocol in which NH_4^+ is the mean value for Groups 1 and 2 of experimental animals.

Fig. 2 is a diagram illustrating arterial glutamine concentration for Groups 1 and 2. Statistical significance ($p < 0.05$) according to the Wilcoxon signed rank test

20   is indicated by "a" -different from baseline; "b"-different from 60 min; "c"-different from 120 min; "d"-different from 180 min, in each group respectively.

Fig. 3 is a diagram illustrating splanchnic glutamine turnover for Groups 1 and 2. Positive values (mean ± SEM) indicate uptake. Statistical significance ($p < 0.05$) according to the Wilcoxon signed rank test is indicated by "b"-different from

25   60 min; "c"-different from 120 min.

Fig. 4 is a diagram illustrating hind leg glutamine turnover for Groups 1 and 2. Negative values (mean ± SEM) indicate release.

DESCRIPTION OF PREFERRED EMBODIMENTS

Experimental animals.

5 Sixteen piglets of a mixed breed (Hampshire, Yorkshire and Swedish land race), of both sexes, weighing 20.9 to 33.2 kg (mean weight 25.6 kg), were used in this study. Food was withheld from the animals for twelve hours prior to the experiment, but they had free access to water.

Anaesthesia.

10 Anaesthesia was induced by an intramuscular injection of xylazine 2.2 $mg \cdot kg^{-1}$, tiletamine 3 $mg \cdot kg^{-1}$ + zolazepam 3 $mg \cdot kg^{-1}$ and atropine 0.04 $mg \cdot kg^{-1}$. In addition, all animals were given an intravenous bolus of morphine 1 $mg \cdot kg^{-1}$ and, following tracheotomy, pancuronium bromide 0.3 $mg \cdot kg^{-1}$. For continuation, an infusion of sodium pentobarbital 8 $mg \cdot kg^{-1} \cdot h^{-1}$ and pancuronium bromide 0.26

15 $mg \cdot kg^{-1} \cdot h^{-1}$ was started immediately after induction. During the experiment, the animals received 10 $mL \cdot kg^{-1}$ of dextran 70 and 18 $mL \cdot kg^{-1} \cdot h^{-1}$ of isotonic saline to maintain normovolaemia. After the last measurements, still under anaesthesia, the animals were killed with an overdose of potassium chloride. After induction of anaesthesia the animals were tracheotomised and ventilated through an 8 mm

20 endotracheal tube (Mallincrodt Laboratories, Athlone, Ireland) with a Servo ventilator 900C (Siemens-Elema, Solna, Sweden). Ventilation was maintained at 25 breaths per minute with a positive end-expiratory pressure of 5 cm of H_2O. Tidal volume was adjusted to keep arterial PCO_2 between 5.0 and 6.0 kPa. The inspired gas mixture during the surgical procedures was 30 % oxygen in nitrous oxide and 30

25 % oxygen in air during the experimental period. The body temperature was kept

stable by means of a thermostat controlled heating pad and warmed intravenous

infusions. After skin incisions, a catheter was introduced in the left external jugular

vein and advanced to the right hepatic vein under fluoroscopic control. Its position

was confirmed by a contrast injection. The right external jugular vein was used for

5   placement of a central venous catheter and a 7F pulmonary artery thermodilution

catheter. An arterial catheter was inserted in a subclavian branch and advanced to a

central position. Through a small suprapubic incision, a urinary catheter was placed

in the bladder. A cutdown was made to place an ultrasonic flow probe (Transonic

Systems Inc., Ithaca, N.Y., USA) around the femoral artery and to cannulate the

10   femoral vein for blood sampling.

Blood analyses and other measurements.

        Arterial blood gases were analysed on an ABL300/OSM3 system

(Radiometer, Copenhagen, Denmark). Amino acid concentration were analysed in

arterial, hepatic and femoral venous plasma on a Pharmacia LKB Biochrom 20

15   Amino Acid Analyser (Pharmacia, Uppsala, Sweden), using continuous flow ion

exchange chromatography. The column eluate was mixed with ninhydrin reagent for

amino acid detection. Arterial and venous plasma urea and ammonium was analysed

with routine enzymatic methods on a Hitachi 717 Automatic Analyser (Hitachi Ltd.,

Tokyo, Japan). Blood glucose was analysed on a Reflolux® II (Boehringer

20   Mannheim, Germany), using the glucose-oxidase/peroxidase reaction. Arterial and

hepatic venous blood was drawn for calculations of splanchnic blood flow. ECG,

arterial and central venous pressure and cardiac output, were monitored and

displayed on a Sirecust 1281 (Siemens Medical Electronics Inc., Danvers, MA,

USA). Cardiac output was measured with the thermodilution technique using 10 mL

25   of iced normal saline as indicator. The mean value of at least three measurements

was adopted.

Calculation of splanchnic blood flow.

Calculation of splanchnic blood flow was carried out according to the constant dye infusion technique (10). The dye, indocyanine green (PULSION, Medical Systems, Munich, Germany), was given intravenously at a rate of 0.17 mg·min⁻¹, which gave a stable arterial concentration of indocyanine green. Arterial and hepatic venous blood was drawn simultaneously and after centrifugation at 3000 rpm for 20 min, the indocyanine green plasma concentration was determined spectrophotometrically (Hitachi 101, Hitachi Ltd., Tokyo, Japan) at a wavelength of 805 nm. Splanchnic plasma flow was calculated according to a formula derived from Fick's principle:

$$F_P = \frac{I}{(C_a - C_v)}$$

Arterial blood hematocrit (Erythrocyte Volume Fraction, EVF) was measured and the value added to the formula in order to calculate splanchnic blood flow:

$$F_B = \frac{I}{(C_a - C_v)(1 - EVF)}$$

where F_P = splanchnic plasma flow (mL·min⁻¹), F_B = splanchnic blood flow (mL·min⁻¹), I = indocyanine green infusion rate (mg·min⁻¹), C_a = arterial plasma concentration of indocyanine green (mg·mL⁻¹), C_v = hepatic venous plasma concentration of indocyanine green (mg·mL⁻¹). Femoral artery plasma flow was calculated as blood flow · (1-EVF). The turnover of amino acids, ammonium and urea were calculated as plasma flow times the arterio-venous plasma concentration difference with negative values indicating release and positive values uptake.

Experimental protocol.

After anaesthesia and surgical preparation the piglets were allowed a stabilisation period of one hour and randomly assigned to either Group 1 or Group 2.

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Blood sampling, measurements and pressure readings were made at 0 min (baseline),
and at four different dosages in each Group, after 60 (dosage 1), 120 (dosage 2), 180
(dosage 3) and 240 min (dosage 4). The timeline and interventions of the experiment
is shown in Fig. 1. It should be pointed out that during the first hour of the study

5   period ammonium chloride alone was administered in Group 1 and α-KGA alone in
Group 2. The basal infusion rate of ammonium, aiming at a base excess (BE) of -6
$mmol \cdot L^{-1}$ at the end of the experiment, was calculated according to the formula: NH_4^+
$(mmol) = 0.3 \cdot (BE+(-6)) \cdot kg$ body weight, where BE was the arterial base excess value
at the baseline measurements.

10   Group 1: Eight animals receiving an infusion of NH4Cl mixed with normal
saline, at a constant rate of 12.3 $\mu mol \cdot kg^{-1} \cdot min^{-1}$ for 240 minutes, commencing after
the baseline measurements (0 min). An infusion of α-KGA (Sigma Chemical Co, St
Louis, MO, USA), dissolved normal saline, was started after the 60 min
measurement, at a rate of 2.85 $\mu mol \cdot kg^{-1} \cdot min^{-1}$ during the first (60-120 min), 5.7

15      $\mu mol \cdot kg^{-1} \cdot min^{-1}$ during the second (120-180 min) and 11.4 $\mu mol \cdot kg^{-1} \cdot min^{-1}$ during the
third (180-240 min) hour of infusion.

Group 2: Eight animals receiving a constant infusion of α-KGA at a rate of
2.85 $\mu mol \cdot kg^{-1} \cdot min^{-1}$ for 240 minutes, commencing after the baseline measurements
(0 min) and an infusion of NH_4Cl started after the 60 min measurement. During the

20   first hour of infusion (60-120 min) the rate was 12.7 $\mu mol \cdot min^{-1} \cdot kg^{-1}$, 25.5
$\mu mol \cdot kg^{-1} \cdot min^{-1}$ during the second hour (120-180 min) and 51.0 $\mu mol \cdot kg^{-1} \cdot min^{-1}$
during the last hour (180-240 min) of infusion.

Statistics.

The data are presented as mean ± SEM. Due to the small sample sizes in the

25   study Groups we did not assume that the data were normally distributed. We
therefore used nonparametric statistical tests. The Wilcoxon signed rank test was

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used for paired comparisons within each Group. Correlation between variables was tested with the Spearman rank correlation coefficient test. Differences were considered statistically significant if $p < 0.05$. The statistical calculations were performed with StatView® 5.0 (SAS Institute Inc., Cary, NC, USA) computer software.

Blood gases and haemodynamics.

Blood gas and hemodynamic variables are presented in Table 1.1 and 1.2. In Group 1 arterial pH decreased from baseline 7.46 ± 0.01 to 7.30 ± 0.01 ($p = 0.012$) at the end of the experiment, and in Group 2 from 7.47 ± 0.004 to 7.29 ± 0.01 ($p = 0.012$). Baseline arterial PCO_2 in Group 1 was 5.28 ± 0.07 kPa and 5.31 ± 0.06 kPa in Group 2 and normoventilation was maintained for the whole experimental period. In Group 1, baseline cardiac output (C.O.) was 140 ± 10 mL·min^{-1}·kg^{-1}, and splanchnic blood flow 51 ± 7 mL·min^{-1}·kg^{-1}, and it did not change significantly. In Group 2, however, C.O. decreased after 60 min compared to the baseline ($p = 0.025$) C.O. of 157 ± 13 mL·min^{-1}·kg^{-1}, after which it resumed the baseline level. In Group 2, the baseline splanchnic blood flow of 53 ± 7 mL·min^{-1}·kg^{-1} was stable until the 180 min measurement when there was an increase ($p = 0.017$) which was not present at the last measurement. In Group 1, baseline femoral artery blood flow was 6.0 ± 0.4 mL·min^{-1}·kg^{-1} and there was a significant decrease to 4.7 ± 0.4 mL·min^{-1}·kg^{-1} after 60 min ($p = 0.018$) and it continued to decrease until 120 min ($p = 0.012$) at which level it remained during the rest of the experiment. In Group 2 the baseline value was 7.4 ± 0.8 mL·min^{-1}·kg^{-1} and there was a decrease after 120 min ($p = 0.012$) which, as in Group 1, remained stable onwards to the end of the experiment.

Amino acids, ammonium, urea and glucose.

Arterial and venous concentration data are shown in Table 2.1 and 2.2

Glutamine. In Group 1, the arterial glutamine concentration was increased after 60 min (p = 0.012) compared to 384 ± 34 $\mu mol \times L^{-1}$ at baseline. Glutamine concentration at the other dosages were not significantly different from baseline. In Group 2 the baseline value was 397 ± 26 $\mu mol \times L^{-1}$ and an initial decrease was seen after 60 min (p = 0.017), and subsequently there were stepwise increasing glutamine concentrations for each dosage increment. Interestingly, in Group 2, there was a significant correlation (r_s = -0.77; p < 0.0001) between arterial glutamine concentration and arterial pH. No such correlation was seen in Group 1 (r_s = -0.28; p = 0.089).

Glutamate. In Group 1 the initial arterial concentration of glutamate was 181 ± 18 $\mu mol \times L^{-1}$ and an increase was observed at 180 min (p = 0.036) compared to the baseline value. In Group 2 there was an elevated glutamate concentration after 120, 180 and 240 min compared to the initial 241 ± 23 $\mu mol \times L^{-1}$.

Alanine. The arterial alanine concentration in Group 1 was significantly lower (p < 0.05) at all the studied dosages compared to the baseline value (503 ± 51 $\mu mol \times L^{-1}$), and at 60 min compared to 240 min. In Group 2 there was a significant decrease after 60, 180 and 240 min compared to 506 ± 38 $\mu mol \times L^{-1}$ at baseline, and also at 240 min (p < 0.05) compared to 60 and 180 min.

Arginine. There was a marked increase in arterial arginine concentration in both Groups. From 71 ± 6 $\mu mol \times L^{-1}$ to 127 ± 8 $\mu mol \times L^{-1}$ (+ 44 %, p = 0.012) in Group 1 and 77 ± 8 $\mu mol \times L^{-1}$ to 128 ± 6 $\mu mol \times L^{-1}$ (+ 40 %, p = 0.017) in Group 2.

α-Ketoglutarate is a precursor of arginine and may as such be responsible for the 44% (Group 1) and 40% (Group 2) increase in arterial arginine concentration. Also, it was reported in a human study by Reaich et al. (20) that ammonium chloride induced acidosis was found to increase the plasma level of arginine and other amino acids but, in contrast to what is disclosed here, not of glutamine. There was a slight tendency for splanchnic uptake of arginine to switch to a net release after 180 min in

Group 2 while in Group 1 no apparent effect on splanchnic turnover was observed.
Hind leg exchange data was similar to that of the splanchnic bed with a significant
switch to release after 180 min that was not present at the final measurement. Again,
there was no effect on the hind leg uptake of arginine in Group 1.

5   Ammonium. The arterial ammonium concentration in Group 1, 36 ± 2
$\mu mol \times L^{-1}$, increased after 60 min infusion to a level which was maintained for the
rest of the study period. The baseline ammonium concentration in Group 2 was $41 \pm$
$4 \mu mol \times L^{-1}$. The ammonium infusion started after the 60 min measurement and
there was an increase after each change of the dose rate.

10   Urea. In Group 1 the arterial urea concentration did not change during the
experiment, compared to $3.4 \pm 0.4 \mu mol \times L^{-1}$ at baseline. In Group 2 the arterial urea
concentration at baseline, $2.9 \pm 0.2 \mu mol \times L^{-1}$, was increased to 4.3 ± 0.2 (p = 0.012)
after 240 min. Compared to the 60 min value, the point when the ammonium
infusion was started, the urea concentration increased with every new dosage.

15   Glucose. The baseline blood glucose level was 6.0 ± 0.4 and 5.7 ± 0.5
$\mu mol \times L^{-1}$ in Group 1 and Group 2, respectively. In Group 1 there was a decrease
after 180 and 240 min compared to baseline, and in Group 2 there were no changes
compared to baseline but a decrease at 180 and 240 min compared to the 60 min
value.

20   Amino acid, ammonium and urea turnover. Values are shown in Table 3.1
and 3.2. At baseline, splanchnic glutamine uptake was $2.5 \pm 0.6 \mu mol \cdot min^{-1} \cdot kg^{-1}$ in
Group 1, and it was not affected by the different dose levels of the substrate infusion.
In Group 2 there was a splanchnic uptake at baseline of $2.6 \pm 0.8 \mu mol \cdot min^{-1} \cdot kg^{-1}$
which was not significantly changed by the different dose rates. There was,

25   however, a higher uptake after 180 (p = 0.017) and 240 min (p = 0.012) compared to
the uptake at 120 min and at 240 min compared to 60 min. From hind leg skeletal

muscle there was a net release of glutamine in both Groups which was not affected by the different dose rates.

Glutamate turnover. There was a splanchnic release of 5.04 ± 0.49 $\mu mol \cdot min^{-1} \cdot kg^{-1}$ glutamate in Group 1 at baseline. The glutamate release at 240 min was significantly lower than was seen with all other dosages. In Group 2, the different dosages did not change the baseline glutamate release of 6.58 ± 0.52 $\mu mol \cdot min^{-1} \cdot kg^{-1}$. Skeletal muscle turnover of glutamate at baseline presented a net uptake of 0.19 ± 0.03 $\mu mol \cdot min^{-1} \cdot kg^{-1}$ in Group 1 and 0.30 ± 0.05 $\mu mol \cdot min^{-1} \cdot kg^{-1}$ in Group 2. In Group 1, the different dosages did not change the glutamate turnover, and in Group 2 there was a greater uptake after 120 min compared to 180 min, but no differences compared to baseline.

Alanine turnover. In both Groups, there was a splanchnic uptake of alanine at baseline, 3.46 ± 0.89 and 4.24 ± 1.14 $\mu mol \cdot min^{-1} \cdot kg^{-1}$ in Group 1 and 2, respectively, and it remained unaltered during the experimental period. In skeletal muscle there was a release of alanine, 0.19 ± 0.03 and 0.27 ± 0.13 $\mu mol \cdot min^{-1} \cdot kg^{-1}$, respectively, in Group 1 and 2. It was not altered by the different dose levels.

Arginine turnover. There was a splanchnic uptake of arginine in both Groups, 0.06 ± 0.21 $\mu mol \cdot min^{-1} \cdot kg^{-1}$ and 0.39 ± 0.36 $\mu mol \cdot min^{-1} \cdot kg^{-1}$, respectively, at baseline; no significant changes occurred during the study period. Hind leg uptake of arginine was 0.01 ± 0.03 $\mu mol \cdot min^{-1} \cdot kg^{-1}$ in Group 1 and 0.09 ± 0.04 $\mu mol \cdot min^{-1} \cdot kg^{-1}$ in Group 2. No effect on hind leg uptake was observed in Group 1 whereas in Group 2 a switch from uptake to release was seen after 180 min ($p < 0.05$).

Urea turnover. Group 1 demonstrated a net release of urea from the splanchnic region, and the baseline level 3.2 ± 1.3 $\mu mol \cdot min^{-1} \cdot kg^{-1}$, was not significantly changed during the study period. At 180 min there was, however, an increased release compared to the previous dose level ($p = 0.028$). In Group 2 there

was a release of 6.0 ± 3.2 $\mu mol \cdot min^{-1} \cdot kg^{-1}$ at baseline and no significant changes in splanchnic urea turnover compared to the baseline condition were recorded.

Ammonium turnover. At baseline there was a small splanchnic uptake of ammonium in both Groups, 0.52 ± 0.20 $\mu mol \cdot min^{-1} \cdot kg^{-1}$ and 0.53 ± 0.22 $\mu mol \cdot min^{-1} \cdot kg^{-1}$, in Group 1 and 2, respectively. In Group 1 there was a significant increase after 60 min which was maintained for the duration of the study period with a peak splanchnic uptake of 4.1 ± 1.0 $\mu mol \cdot min^{-1} \cdot kg^{-1}$ after 180 min. Group 2 presented an increased uptake after 120 min and for each dosage there was a concomitant increase in the splanchnic uptake. Hind leg ammonium turnover in Group 1 was near zero at baseline with only a small uptake of 0.02 ± 0.03 $\mu mol \cdot min^{-1} \cdot kg^{-1}$ which was significantly increased after 60, 120 and 180 min and then decreased to almost baseline level, 0.05 ± 0.09 $\mu mol \cdot min^{-1} \cdot kg^{-1}$, after 240 min. Hind leg turnover in Group 2 was similar to Group 1 at baseline and it was significantly increased after 120 ($p = 0.012$) and 240 ($p = 0.012$) minutes compared to the baseline value. Compared to the 60 min measurement ammonium uptake was higher at all of the ensuing dosages. Significantly higher uptake was also seen at 240 min compared to the 120 min measurement.

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Table 1.1: Dosages effects of α-KA and ammonium chloride on blood gas and hemodynamic variables in group 1(n = 8).

	Baseline 0 min	Dosage 1 60 min	Dosage 2 120 min	Dosage 3 180 min	Dosage 4 240 min
Arterial pH	7.46±0.01	7.43±0.01 a	7.39±0.01 ab	7.35±0.01abc	7.30±0.01 abcd
Base excess μmol·L^{-1}	3.9±0.5	1.7±0.3 a	-0.5±0.3 ab	-2.9±0.4 abc	-5.6±0.4 abcd
PaCO$_2$ kPa	5.28±0.07	5.18±0.06	5.37±0.06 b	5.48±0.07 ab	5.44±0.07
C.O. ml·min^{-1}·kg^{-1}	140±10	138±17	147±17	157±16	163±17
Spl. blood flow ml·min^{-1}·kg^{-1}	51±7	43±5	44±6	54±5 b	49±4
Leg blood flow ml·min^{-1}·kg^{-1}	6.0±0.4	4.7±0.4 a	3.9±0.3 ab	3.5±0.2 ab	3.4±0.3 ab

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Values are mean $\pm$ SEM. Statistical significance ($p < 0.05$) according to the Wilcoxon signed rank test is indicated by "a" -different from baseline; "b"-different from 60 min; "c"-different from 120 min; "d"-different from 180 min. Dose rates for group 1: Dosage 1 (0-60 min) - NH_4^+, 12.3 $\mu mol \cdot kg^{-1} \cdot min^{-1}$; Dosage 2 (60-120 min) - NH_4^+, 12.3 $\mu mol \cdot kg^{-1} \cdot min^{-1}$ + α-ketoglutarate, 2.85 $\mu mol \cdot kg^{-1} \cdot min^{-1}$; Dosage 3 (120-180 min) - NH_4^+, 12.3 $\mu mol \cdot kg^{-1} \cdot min^{-1} \cdot h^{-1}$ + α-ketoglutarate, 5.7 $\mu mol \cdot kg^{-1} \cdot min^{-1}$; Dosage 4 (180-240 min) - NH_4^+, 12.3 $\mu mol \cdot kg^{-1} \cdot min^{-1}$ + α-ketoglutarate, 11.4 $\mu mol \cdot kg^{-1} \cdot min^{-1}$.

Table 1.2: Dosages effects of α-KA and ammonium chloride on blood gas and hemodynamic variables in group 2 (n = 8).

	Baseline 0 min	Dosage 1 60 min	Dosage 2 120 min	Dosage 3 180 min	Dosage 4 240 min
Arterial pH	7.47±0.004	7.47±0.01	7.42±0.01 ab	7.37±0.01 abc	7.29±0.01 abcd
Base excess $\mu mol \cdot L^{-1}$	5.0±0.5	4.4±0.3	1.7±0.6 ab	-1.8±0.4 abc	-6.3±0.4 abcd
$PaCO_2$ kPa	5.31±0.06	5.27±0.06	5.43±0.09 b	5.42±0.15	5.42±0.11
C.O. $ml \cdot min^{-1} \cdot kg^{-1}$	158±13	144±10 a	151±10	164±11	185±14 bcd
Spl. blood flow $ml \cdot min^{-1} \cdot kg^{-1}$	53±7	49±6	50±5	64±5 abc	73±11 c
Leg blood flow $ml \cdot min^{-1} \cdot kg^{-1}$	7.4±0.8	6.0±0.5 a	4.7±0.3 ab	4.1±0.2 ab	4.3±0.3 ab

Values are mean ± SEM. Statistical significance ($p < 0.05$) according to the Wilcoxon signed rank test is indicated by "a" -different from baseline; "b"-different from 60 min; "c"-different from 120 min; "d"-different from 180 min. Dose rates for Group 2: Dosage 1 (0-60 min) - α-ketoglutarate, 2.85 $\mu mol \cdot kg^{-1} \cdot min^{-1}$; Dosage 2 (60-120 min) - α-ketoglutarate, 2.85 $\mu mol \cdot kg^{-1} \cdot min^{-1}$ + NH_4^+, 12.7 $\mu mol \cdot kg^{-1} \cdot min^{-1}$; Dosage 3 (120-180 min) - α-ketoglutarate, 2.85 $\mu mol \cdot kg^{-1} \cdot min^{-1}$ + NH_4^+, 25.5 $\mu mol \cdot kg^{-1} \cdot min^{-1}$; Dosage 4 (180-240 min)- α-ketoglutarate, 2.85 $\mu mol \cdot kg^{-1} \cdot min^{-1}$ + NH_4^+, 51.0 $\mu mol \cdot kg^{-1} \cdot min^{-1}$.

Table 2.1: Dosages effects of α-KA and NH$_4$Cl on arterial amino acid, NH$_4$, urea and glucose concentrations in Group 1 (n = 8).

	Baseline 0 min	Dosage 1 60 min	Dosage 2 120 min	Dosage 3 180 min	Dosage 4 240 min
Glutamine μmol·L^{-1}	384±34	450±26 a	447±34	455±45	504±52
Glutamate μmol·L^{-1}	181±18	191±20	198±17	209±16	213±18
Alanine μmol·L^{-1}	503±51	412±44 a	368±45 ab	356±44 ab	344±41 ab
Arginine μmol·L^{-1}	71±6	80±8	96±8 ab	117±7 abc	127±8 abc
Total AA μmol·L^{-1}	3186±167	3034±139	2958±140	3080±166	3160±165
NH$_4^+$ μmol·L^{-1}	36±2	135±14 a	141±13 a	145±11 a	115±22 a
Urea mmol·L^{-1}	3.4±0.4	3.4±0.3	3.5±0.3	3.5±0.2	3.6±0.3
Glucose mmol·L^{-1}	6.0±0.4	5.5±0.5	4.8±0.6	4.6±0.6 a	5.2±0.5 a

Values are mean ± SEM. Statistical significance ($p < 0.05$) according to the Wilcoxon signed rank test is indicated by "a" -different from baseline; "b"-different from 60 min; "c"-different from 120 min; "d"-different from 180 min. Dose rates for Group 1: Dosage 1 (0-60 min) - NH_4^+, 12.3 $\mu mol \cdot kg^{-1} \cdot min^{-1}$; Dosage 2 (60-120 min) - NH_4^+, 12.3 $\mu mol \cdot kg^{-1} \cdot min^{-1}$ + α-ketoglutarate, 2.85 $\mu mol \cdot kg^{-1} \cdot min^{-1}$; Dosage 3 (120-180 min) - NH_4^+, 12.3 $\mu mol \cdot kg^{-1} \cdot min^{-1} \cdot h^{-1}$ + α-ketoglutarate, 5.7 $\mu mol \cdot kg^{-1} \cdot min^{-1}$; Dosage 4 (180-240 min) - NH_4^+, 12.3 $\mu mol \cdot kg^{-1} \cdot min^{-1}$ + α-ketoglutarate, 11.4 $\mu mol \cdot kg^{-1} \cdot min^{-1}$.

Table 2.2: Dosages effect of α-KA and NH$_4$Cl on arterial amino acid, NH$_4$, urea and glucose concentrations in group 2 (n = 8).

	Baseline 0 min	Dosage 1 60 min	Dosage 2 120 min	Dosage 3 180 min	Dosage 4 240 min
Glutamine μmol·L^{-1}	397±26	361±24 z	451±27 ab	521±29 abc	621±37 abcd
Glutamate μmol·L^{-1}	241±23	264±32	287±28 ab	284±25 a	296±24 a
Alanine μmol·L^{-1}	506±38	462±34	436±37	392±32 a	353±27 abd
Arginine μmol·L^{-1}	77±8	75±5	95±7 b	112±7 ab	128±6 abcd
Total AA μmol·L^{-1}	3198±167	3044±158	3244±178	3270±154	3233±119
NH$_4^+$ μmol·L^{-1}	41±4	43±4	147±10 ab	277±29 abc	728±135 abcd
Urea mmol·L^{-1}	2.9±0.2	2.7±0.2	2.9±0.2 b	3.3±0.2 bc	4.3±0.2 abcd
Glucose mmol·L^{-1}	5.7±0.5	5.6±0.4	5.3±0.4	4.9±0.5 b	4.7±0.4 b

Values are mean ± SEM. Statistical significance ($p < 0.05$) according to the Wilcoxon signed rank test is indicated by "a" -different from baseline; "b"-different from 60 min; "c"-different from 120 min; "d"-different from 180 min. Dose rates for Group 2: Dosage 1 (0-60 min) - α-ketoglutarate, 2.85 $\mu mol \cdot kg^{-1} \cdot min^{-1}$; Dosage 2 (60-120 min) - α-ketoglutarate, 2.85 $\mu mol \cdot kg^{-1} \cdot min^{-1}$ + NH_4^+, 12.7 $\mu mol \cdot kg^{-1} \cdot min^{-1}$; Dosage 3 (120-180 min) - α-ketoglutarate, 2.85 $\mu mol \cdot kg^{-1} \cdot min^{-1}$ + NH_4^+, 25.5 $\mu mol \cdot kg^{-1} \cdot min^{-1}$; Dosage 4 (180-240 min)- α-ketoglutarate, 2.85 $\mu mol \cdot kg^{-1} \cdot min^{-1}$ + NH_4^+, 51.0 $\mu mol \cdot kg^{-1} \cdot min^{-1}$.

Table 3.1: Turnover effects for different dosages of a-ketoglutaric acid and ammonium chloride in group 1 (n = 8).

		Baseline 0 min	Dosage 1 60 min	Dosage 2 120 min	Dosage 3 180 min	Dosage 4 240 min
Glutamine	splanchinc	2.52±0.60	2.59±0.56	2.82±0.32	3.50±0.47	3.79±0.54
	hind leg	-0.04±0.05	-0.09±0.04	-0.10±0.05	-0.14±0.04	-0.10±0.05
Glutamate	splanchinc	-5.04±0.49	-4.32±0.28	-4.33±0.34	-4.78±0.46	-3.60±0.25 abcd
	hind leg	0.19±0.03	0.22±0.03	0.19±0.03	0.17±0.03	0.16±0.03
Alanine	splanchinc	3.46±0.89	2.22±0.28	2.73±0.58	3.14±0.49	3.41±0.73
	hind leg	0.19±0.03	-0.13±0.04	-0.21±0.14	-0.11±0.04	-0.15±0.05
Arginine	splanchinc	0.06±0.21	-0.23±0.10	0.03±0.15	0.11±0.23	-0.06±0.22
	hind leg	0.01±0.03	0.01±0.005	0.01±0.02	0.01±0.01	-0.01±0.02
Total AA	splanchinc	6.21±2.54	3.93±2.08	4.35±0.98	5.41±1.43	7.19±2.64
	hind leg	-0.01±0.32	0.12±0.23	0.09±0.25	-0.10±0.16	-0.10±0.17
NH_4^+	splanchinc	0.52±0.20	3.09±0.28 a	3.34±0.19 a	4.10±0.34 ab	2.76±0.57 a
	hind leg	0.02±0.01	0.22±0.03 a	0.17±0.02 a	0.13±0.03ab	0.05±0.03 bcd

		Baseline 0 min	Dosage 1 60 min	Dosage 2 120 min	Dosage 3 180 min	Dosage 4 240 min
FE(%)-NH_4^+	splanchinc	37±11	81±4 a	77±6 a	74±6 a	65±5 ab
	hind leg	12±6	46±3 a	40±4 a	34±3 a	8±9 bcd
Urea	splanchinc	-3.2±1.3	-3.2±1.4	-1.1±1.0	-6.4±1.5 c	-2.2±1.6
	hind leg	0.3±0.2	0.2±0.2	0.6±0.1	0.1±0.2	-0.1±0.3 c

Values are mean ± SEM. Statistical significance ($p < 0.05$) according to the Wilcoxon signed rank test is indicated by "a" -different from baseline; "b"-different from 60 min; "c"-different from 120 min; "d"-different from 180 min. Dose rates for Group 1: Dosage 1 (0-60 min) - NH_4^+, 12.3 $\mu mol \cdot kg^{-1} \cdot min^{-1}$; Dosage 2 (60-120 min) - NH_4^+, 12.3 $\mu mol \cdot kg^{-1} \cdot min^{-1}$ + α-ketoglutarate, 2.85 $\mu mol \cdot kg^{-1} \cdot min^{-1}$; Dosage 3 (120-180 min) - NH_4^+, 12.3 $\mu mol \cdot kg^{-1} \cdot min^{-1} \cdot h^{-1}$ + α-ketoglutarate, 5.7 $\mu mol \cdot kg^{-1} \cdot min^{-1}$; Dosage 4 (180-240 min) - NH_4^+, 12.3 $\mu mol \cdot kg^{-1} \cdot min^{-1}$ + α-ketoglutarate, 11.4 $\mu mol \cdot kg^{-1} \cdot min^{-1}$.

Table 3.2.

Turnover effects for different dosages of a-ketoglutaric acid and ammonium chloride in group 2 (n = 8).

Group 2(n=8)

		Baseline 0 min	Dosage 1 60 min	Dosage 2 120 min	Dosage 3 180 min	Dosage 4 240 min
Glutamine	splanchinc	2.63±0.75	2.14±0.31	2.13±0.62	3.82±0.61 c	5.48±1.32bc
	hind leg	-0.15±0.11	-0.09±0.07	-0.17±0.04	-0.24±0.05	-0.19±0.07
Glutamate	splanchinc	-6.58±0.52	-5.83±0.61	-5.23±0.67	-5.94±0.79	-6.16±1.61
	hind leg	0.30±0.05	0.25±0.06	0.34±0.05	0.27±0.03 c	0.28±0.05
Alanine	splanchinc	4.24±1.14	4.11±0.97	2.79±0.68	3.65±0.52	3.85±0.84
	hind leg	-0.27±0.13	-0.20±0.09	-0.17±0.03	-0.15±0.04	-0.15±0.04
Arginine	splanchinc	0.39±0.36	0.26±0.22	0.03±0.15	-0.45±0.41	-0.04±0.25
	hind leg	0.09±0.04	0.03±0.02	0.02±0.02	-0.05±0.04 abc	0.02±0.04 d
Total AA	splanchinc	7.58±4.12	6.18±2.26	2.75±4.43	5.11±2.98	9.84±5.41
	hind leg	-0.23±0.82	-0.36±0.64	0.16±0.28	-0.11±0.21	-0.29±0.35
NH_4^+	splanchinc	0.53±0.22	0.50±0.21	3.72±0.28 ab	9.73±0.57 abc	19.58±2.98 abcd
	hind leg	0.04±0.03	0.01±0.02	0.23±0.03 ab	0.31±0.04abc	0.51±0.14abc.

		Baseline 0 min	Dosage 1 60 min	Dosage 2 120 min	Dosage 3 180 min	Dosage 4 240 min
FE(%)-NH_4^+	splanchinc	27±13	28±10	70±4 ab	77±4 ab	56±7 bd
	hind leg	8±11	5±7	43±4 ab	35±2 b	20±3 bcd
Urea	splanchinc	-6.0±3.2	-4.0±1.2	-3.0±2.8	-2.6±3.3	5.3±4.0
	hind leg	-0.3±0.6	-0.2±0.4	0.2±0.4	0.5±0.2	0.7±0.2 b

Values are mean ± SEM. Statistical significance ($p < 0.05$) according to the Wilcoxon signed rank test is indicated by "a" -different from baseline; "b"-different from 60 min; "c"-different from 120 min; "d"-different from 180 min. Dose rates for Group 2: Dosage 1 (0-60 min) - α-ketoglutarate, 2.85 $\mu mol \cdot kg^{-1} \cdot min^{-1}$; Dosage 2 (60-120 min) - α-ketoglutarate, 2.85 $\mu mol \cdot kg^{-1} \cdot min^{-1}$ + NH_4^+, 12.7 $\mu mol \cdot kg^{-1} \cdot min^{-1}$; Dosage 3 (120-180 min) - α-ketoglutarate, 2.85 $\mu mol \cdot kg^{-1} \cdot min^{-1}$ + NH_4^+, 25.5 $\mu mol \cdot kg^{-1} \cdot min^{-1}$; Dosage 4 (180-240 min)- α-ketoglutarate, 2.85 $\mu mol \cdot kg^{-1} \cdot min^{-1}$ + NH_4^+, 51.0 $\mu mol \cdot kg^{-1} \cdot min^{-1}$.